9/pFTS

10/535654

JC06 Rec'd PCT/PTO 19 MAY 2005

M1071.1932

DESCRIPTION

ANTENNA DEVICE, RADIO DEVICE, AND RADAR

Technical Field

The present invention relates to an antenna device in which the directivity can be electronically controlled, and to a radio device and a radar having the antenna device.

Background Art

Up to now, for example, an antenna device for a milliwave radar detecting a target by using an electromagnetic wave in the milliwave band is disclosed in Patent Document 1 (Japanese Unexamined Patent Application Publication No. 11-127001). In the antenna device shown in this Patent Document 1, a plurality of primary radiators is time-division switched by using dielectric lines and dielectric line switches, and transmission-reception wave beams are scanned such that the position of effective primary radiators is moved in the focus plane of a dielectric lens.

The antenna device shown in Patent Document 1 has the advantage of having a relatively simple structure and performing beam scanning by simple actions. However, in the antenna device shown in Patent Document 1, since beam scanning is performed by mechanical displacement of the position of the primary radiators, there are problems in that it is difficult to increase the speed of beam scanning beyond a certain level, that power consumption

needed for the beam scanning is relatively large, and that operation noise is caused when beam scanning is performed. In addition, since the position of the primary radiators is mechanically displaced, it can be assumed that the life is limited by the wear of sliding portions and the reliability is low when compared with other electronic components.

Furthermore, since the positional displacement of the plurality of primary radiators always has the same pattern, it is impossible to direct the beam in a desired direction and randomly scan beam directions even if required.

Furthermore, since only the relative position of the primary radiators to the lens is displaced, it is impossible to change the radiation pattern of beams.

It is an object of the present invention to provide an antenna device in which the above-described problems are solved, the beam scanning is speeded, power consumption for the beam scanning is reduced, operation noise in the beam scanning is eliminated, the reliability is improved, and, when required, the beam direction can be directed to any direction.

Furthermore, it is another object of the present invention to provide an antenna device in which the above problems are solved and, when required, the radiation pattern of beams can be changed.

Disclosure of Invention

An antenna device of the present invention comprising a resonance element array having a plurality of resonance elements arranged therein, and having a circuit connected to each of the

resonance elements, the circuit provided therein, and the circuit for controlling a resonance frequency of the resonance elements; a primary radiator for radiating an electromagnetic wave for excitation to the resonance element array or for receiving an electromagnetic wave radiated from the resonance elements; and collimating means of a lens or reflector disposed such that the position of the resonance element array is a focus plane.

An antenna device of the present invention comprising a resonance element array having a plurality of resonance elements resonating at a fixed frequency arranged therein, and having variable reactance circuits connected to the resonance elements, respectively, whose reactance changed by an applied voltage, the circuits provided therein; a control portion for controlling a voltage to be applied to the variable reactance circuits; a primary radiator for radiating an electromagnetic wave for excitation to the resonance element array or for receiving an electromagnetic wave radiated from the resonance elements; and collimating means of a lens or reflector disposed such that the position of the resonance element array is a focus plane.

In this way, the directivity of an antenna can be electronically controlled with high freedom such that an arbitrary resonance element out of a plurality of resonance elements existing substantially on the focus plane of collimating means of a lens or reflector are excited. Furthermore, when required, a radiation pattern of beams can be changed such that a plurality of arbitrary resonance elements out of a plurality of resonance elements are simultaneously excited.

Furthermore, in an antenna device of the present invention, by controlling an applied voltage to the variable reactance circuits, the control portion makes resonance elements at fixed positions or in the vicinity of the fixed positions operate as a wave director out of the plurality of resonance elements and changes the resonance elements at the fixed positions to resonance elements at other positions.

In this way, in the plurality of resonance elements of a resonance element array, the resonance frequency of fixed resonance elements is controlled by controlling an applied voltage to the variable reactance circuits connected thereto. Out of the plurality of resonance elements, the resonance elements resonating to the frequency of an electromagnetic wave radiated from the primary radiator operates as a wave director, an electromagnetic wave re-radiated from the resonance elements as a wave director is collimated by the collimating means, and the beam is formed in a direction determined by the positional relation between the resonance elements and the collimating means. Because of the reversibility principle of an antenna, when the antenna device operates as a reception antenna, the same thing can be said.

Accordingly, it is possible to electronically control the directivity direction by controlling an applied voltage to the variable reactance circuits.

Furthermore, in an antenna device of the present invention, the primary radiator contains a plurality of primary radiators so that the radiation position to the resonance element array may be optimized or the position for receiving an electromagnetic wave

radiated from the resonance element array may be optimized. Thus, even if the plurality of resonance elements contained in a resonance element array is widely distributed, resonance elements to be excited can be excited by using a primary radiator situated close to the resonance elements. Furthermore, an electromagnetic wave radiated from fixed resonance elements can be received by the primary radiator close to the resonance elements.

Furthermore, in an antenna device of the present invention, the primary radiator contains an opening hollow resonator and an excitation source for exciting the opening hollow resonator. Thus, the spatial coupling between each resonance element of a resonance element array and an excitation source is easily performed such that only the resonance element array is disposed at the opening portion of the hollow resonator.

Furthermore, in an antenna device of the present invention, the plurality of resonance elements are linear conductors which are substantially perpendicular to the arrangement direction and extend parallel to each other. Thus, the resonance element array can be easily constituted on a dielectric substrate.

Furthermore, in an antenna device of the present invention, the plurality of resonance elements are linear conductors which are substantially 45 degrees tilted to the arrangement direction and extend parallel to each other. Thus, when an electromagnetic wave transmitted by another antenna device constituted in the same way is received from the direction of the front, since the plane of polarization is perpendicular to the plane of polarization of the own antenna device, the affect of crossing polarized waves can

be reduced.

Furthermore, in an antenna device of the present invention, a variable capacitance diode changing the load reactance to the resonance element is contained in the variable reactance circuit, and the control portion applies a reverse bias voltage to the variable capacitance diode.

Furthermore, in an antenna device of the present invention, a switching element for switching the load reactance to the resonance element is contained in the variable reactance circuit, and the control portion applies a control voltage to the switching element.

Furthermore, in an antenna device of the present invention, an MEMS element where the distance between electrodes is changed by a control voltage is contained in the variable reactance circuit, and the control portion applies a control voltage to the MEMS element.

Furthermore, in an antenna device of the present invention, the switching element is an MEMS element where a switching control between electrodes is performed by a control voltage.

Furthermore, in an antenna device of the present invention, the primary radiator is an electronically controlled wave director array antenna in which a feed element is disposed in the center and non-feed elements having a reactance loaded therein are disposed around the feed element. Thus, the radiation pattern of an electromagnetic wave formed in the direction of a resonance element array becomes controllable.

Furthermore, a radio device of the present invention contains

one of the above antenna devices.

Moreover, a radar of the present invention contains one of the above antenna devices.

As described above, according to the present invention, the directivity of an antenna can be electronically controlled with high freedom such that an arbitrary resonance element out of a plurality of resonance elements existing substantially on the focus plane of collimating means of a lens or reflector are excited. Furthermore, when required, a radiation pattern of beams can be changed such that a plurality of arbitrary resonance elements out of a plurality of resonance elements are simultaneously excited.

Furthermore, according to the present invention, by controlling an applied voltage to the variable reactance circuits, since resonance elements at fixed positions operating as a wave director out of the plurality of resonance elements are changed to resonance elements at other positions, the directivity direction of a beam can be electronically controlled and, as required, the beam can be directed to a desired direction and the beam direction can be randomly scanned.

Furthermore, according to the present invention, since the primary radiator contains a plurality of primary radiators so that the radiation position to the resonance element array may be optimized or the position for receiving an electromagnetic wave radiated from the resonance element array may be optimized, even if the plurality of resonance elements in the resonance element array is widely distributed, resonance elements can be excited by

using a primary resonator close to the resonance elements to be excited. Furthermore, since an electromagnetic wave radiated from fixed resonance elements can be received by a primary radiator close to the fixed resonance elements, uniform sensitivities can be realized over a wide range.

Furthermore, according to the present invention, since the primary radiator is constituted by an opening hollow resonator and an excitation source for exciting the opening hollow resonator, the spatial coupling between each resonance element of the resonance element array and the excitation source becomes easy such that only the resonance element array is disposed at the opening portion of the hollow resonator.

Furthermore, according to the present invention, since the plurality of resonance elements are linear conductors which are substantially perpendicular to their arrangement direction and extend parallel to each other, the resonance element array can be easily constituted on a dielectric substrate.

Furthermore, according to the present invention, since the plurality of resonance elements are linear conductors which are substantially 45 degrees tilted to their arrangement direction and extend parallel to each other, when a radio wave transmitted from another antenna device of the same structure from the direction of the front, its plane of polarization is at a right angle to the plane of polarization of the own antenna device and the affect of the crossing planes of polarization can be reduced.

Furthermore, according to the present invention, since a variable capacitance diode changing the load reactance to the

resonance element is contained in the variable reactance circuit, and the control portion applies a reverse bias voltage to the variable capacitance diode, the resonance frequency of a resonance element can be changed over a relatively wide frequency range and, for example, the frequency bands in use can be easily switched.

Furthermore, according to the present invention, since a switching element for switching the load reactance to the resonance element is contained in the variable reactance circuit, and the control portion applies a control voltage to the switching element, the switching between resonant and non-resonant states or between the state of a wave director and the state of a reflector can be easily performed.

Furthermore, according to the present invention, since an MEMS element where the distance between electrodes is changed by a control voltage is contained in the variable reactance circuit and the control portion applies a control voltage to the MEMS element, an antenna device can be miniaturized, a monolithic variable reactance circuit together with a resonance element array can be realized, and the applications in the area of millimeter waves and submillimeter waves become easier.

Furthermore, according to the present invention, since the switching element is an MEMS element where a switching control between electrodes is performed by a control voltage, an antenna device can be miniaturized, a monolithic variable reactance circuit together with a resonance element array can be realized, and the applications in the area of millimeter waves and submillimeter waves become easier.

Furthermore, according to the present invention, since the primary radiator is an electronically controlled wave director array antenna in which a feed element is disposed in the center and non-feed elements having a reactance loaded therein are disposed around the feed element, the radiation pattern of an electromagnetic wave formed in the direction of a resonance element array becomes controllable and, for example, even if a plurality of resonance elements in a resonance element array is formed in a relatively wide area, the problem in that the sensitivity is degraded in the vicinity at both ends of a scanning area can be solved.

Furthermore, since a radio device of the present invention contains one of the above antenna devices, radio communications can be performed such that an antenna is quickly directed in a desired direction with low power consumption.

Moreover, since a radar of the present invention contains one of the above antenna devices, a target can be detected over a wide range through high-speed beam scanning.

Brief Description of the Drawings

Fig. 1 shows the whole structure of an antenna device according to a first embodiment.

Fig. 2 shows the structure of a resonance element array, resonance elements, and variable reactance circuits.

Fig. 3 shows the relation between the position of a resonance element operating as a wave director on a resonance element array and the optical paths collimated by a lens.

Fig. 4 shows an example of a variable reactance circuit.

Fig. 5 shows the structure of a variable reactance circuit of an antenna device according to a second embodiment.

Fig. 6 shows the whole structure of an antenna device according to a third embodiment.

Fig. 7 shows the structure of an antenna device according to a fourth embodiment.

Fig. 8 shows the structure of an antenna device according to a fifth embodiment.

Fig. 9 shows the structure of an antenna device according to a sixth embodiment.

Fig. 10 shows the structure of an antenna device according to a seventh embodiment.

Fig. 11 shows the structure of an antenna device according to an eighth embodiment.

Fig. 12 shows the structure of the portion of a variable reactance circuit of the antenna device.

Fig. 13 shows the structure of an antenna device according to a ninth embodiment.

Fig. 14 shows the structure of a radio device according to a tenth embodiment.

Fig. 15 shows the structure of a radar according to an eleventh embodiment.

Best Mode for Carrying Out the Invention

The structure of an antenna device according of a first embodiment is described with reference to Figs. 1 to 4.

Fig. 1 shows the whole structure of the antenna device. Here, reference numeral 1 represents a primary radiator in a horn antenna and reference numeral 200 represents a resonance element array. In this resonance element array 200, a plurality of resonance elements are provided in a array as will be described later. When this antenna device is used as a transmission antenna, the primary radiator 1 radiates an electromagnetic wave for excitation.

The primary radiator 1 radiates an electromagnetic wave of a linearly polarized wave in the TE10 mode, for example. (B) in Fig. 1 shows the radiation pattern of the primary radiator 1. In this way, although the primary radiator 1 has the directivity in the direction of the resonance element array 200, it gives a substantially uniform electric power to the plurality of resonance elements provided in the resonance element array 200.

Out of the plurality of resonance elements provided in the resonance element array 200, fixed resonance elements are resonant with the frequency of the electromagnetic wave radiated from the primary radiator 1 and function as a wave director.

In (A) of Fig. 1, reference numeral 3 represents a lens made of a dielectric material and having the resonance element array 200 as a focal plane. Since the plurality of resonance elements in the resonance element array 200 is in the focal plane of the lens 3, the direction of a beam is determined in accordance with the position of resonance elements in resonance (that is, which function as a wave director) out of the plurality of resonance elements.

Fig. 2 shows the structure and function of the above resonance element array. (A) of Fig. 2 is a top view when the resonance element array 200 is viewed from the side of the lens 3. In the resonance element array 200, the plurality of resonance elements 201, each of which is made of a linear conductor, formed on one surface of a dielectric substrate 203 are arranged so as to be parallel to each other. These linear conductors are disposed so as to be parallel to the direction of a polarized wave in the TE10 mode radiated from the primary radiator.

Furthermore, a variable reactance circuit 202 is provided substantially in the middle of a resonance element 201. A control portion 4 selectively gives a control voltage to each variable reactance circuit 202 of the resonance elements 201a to 201k through a control signal line 9. For example, when the resonance element 201f is made completely resonant or substantially resonant at a frequency in use and the other resonance elements 201a to 201e are made non-resonant, the resonance element 201f functions as a wave director. In the same way, for example, when the resonance element 201d is made completely resonant or substantially resonant and the remaining resonance elements 201a to 201c and 201e to 201 k are made non-resonant, the resonance element 201d functions as a wave director.

Because of this, the above resonance elements which are completely resonant or substantially resonant are excited by an electromagnetic wave radiated from the primary radiator and re-radiate an electromagnetic wave. That is, the resonance elements operate just like a primary radiator for the lens.

Moreover, a resonance element may be made to operate as a reflector at a frequency in use such that the resonance frequency of the resonance element which is made non-resonant is set to be a fixed ratio lower then the frequency in use.

(B) of Fig. 2 shows that the resonance element 201d operates as a wave director. Thus, an electromagnetic wave is re-radiated from the resonance element 201d excited by the primary radiator 1 and is collimated by the lens 3 shown in Fig. 1.

Fig. 3 shows examples where the direction of a beam changes in accordance with the position of a resonance element operating as a wave director out of the plurality of resonance elements provided in the resonance element array 200. In these examples, when the resonance element 201f is excited by an electromagnetic wave from the primary radiator and operates as a wave director, the beams in the directions shown by optical paths 5f, that is, in the direction of the front are formed. Furthermore, when the resonance element 201d is excited by an electromagnetic wave from the primary radiator and operates as a wave director, the beams in the direction of optical paths 5d, that is, in the direction θ tilted from the direction to the front are formed.

Since the position of the above resonance elements operating as a wave director can be electronically determined, it becomes able to direct a beam in a desired direction or randomly to scan the direction of a beam when necessary.

Furthermore, the number of resonance elements which are made to operate as a wave director is not limited to be single; out of the arranged plurality of resonance elements, two or more

consecutive resonance elements are made to operate as a wave director, and the remaining resonance elements may be made to operate as a reflector. In this way, the width of a radiation pattern of beams can be widened.

Furthermore, when a plurality of resonance elements are made to operate as a wave director, not resonance elements at consecutive positions, but, when necessary, resonance elements positioned at intervals may be made as a wave director. In this way, a radiation pattern of beams which have been collimated may be changed in various ways.

Fig. 4 shows a more concrete example of the variable reactance circuit portion shown in (A) of Fig. 2. In this example, the variable reactance circuit 202 is constituted such that two sets of circuits each of which is made up of a variable diode Dr, a resistor R, and a capacitor C are symmetrically provided and that the cathode side of the two varactor diodes Dv is the end portions of the resonance element 201, respectively, and the anode side is grounded. Here, the resistor R and the capacitor C constitute a filter which prevents high-frequency signals from leaking to the control portion 4.

Because of such a structure, a capacity loaded antenna in which a varactor diode Dv is loaded between the end portion of the resonance element 201 of a linear conductor and the ground is provided. The capacitance generated between the anode and cathode of the varactor diode Dv is changed by the control voltage applied from the control portion 4. Therefore, the capacitance value of the loaded capacitance of the resonance element 201 changes in

accordance with the control voltage applied from the control portion 4. That is, the equivalent electric length of the resonance element 201 changes. For example, the larger the reverse bias voltage to the varactor diode Dv (the deeper the bias), the smaller the capacitance value of the varactor diode Dv, and as a result, the resonance frequency of the resonance element 201 increases. In contrast with this, the smaller the reverse bias voltage to the varactor diode Dv (the shallower the bias), the larger the capacitance value of the varactor diode Dv, and as a result, the resonance frequency of the resonance element 201 decreases.

In this way, the resonance frequency of the resonance element can be controlled by the control voltage give by the control portion 4.

Moreover, in the example shown in Fig. 4, although a varactor diode is used in the variable reactance circuit, the electrode-to-electrode distance is controlled such that an MEMS (microelectromechanical system) element is used and the drive voltage is applied, and as a result, the reactance may be changed.

As is described above, although a primary radiator having only a relatively low gain is used, the position of resonance elements operating as a wave director is electronically determined in a resonance element array, and a high gain beam is formed and the radiation direction can be changed such that an electromagnetic wave radiated from the resonance element is collimated by using a lens having a focus plane at the position of a resonance element array. Accordingly, the antenna device can be managed with one

system of a high-frequency circuit portion, different from the phased array antenna constituted as a related electronically controlled antenna. That is, since basically only a single primary radiator is used, a low-cost and small antenna device of lower power consumption can be utilized when compared with the phased array antenna.

Moreover, in the example shown in Fig. 1, an ordinary convex lens is used as a dielectric lens, but a lighter and smaller antenna device may be realized by using a Fresnel lens.

Next, the structure of an antenna device according to a second embodiment is shown in Fig. 5. Different from the antenna device of the first embodiment shown in Fig. 4, in this example, switching circuits 204, switching the load capacitance to the resonance element 201 in two ways by application of a control voltage, are provided in the variable reactance circuit 202. (A) of Fig. 5 shows its schematic diagram and (B) is its concrete circuit diagram.

The variable reactance circuit 202 is composed of capacitances C1 and switching circuits 204, and a diode D1 as a switching element is provided in the switching circuit 204. When no control voltage is applied or a voltage is applied so that the diode D1 may be reverse biased, the diode D1 is turned off and only the capacitor C1 is loaded on the resonance element 201. When a fixed positive voltage is applied as a control voltage, the diode D1 is turned on and the capacitors C1 and C2 in parallel are loaded on the resonance element 201. Accordingly, the load capacitance changes by switching the control voltage and the resonance

frequency of the resonance element 201 changes in two ways. Moreover, an inductor L1 and a capacitor C3 constitute a filter circuit, preventing high-frequency signals from leaking to the control portion.

The physical length of the resonance element 201 and the capacitance values of the capacitors C1 and C2 are set so that the resonance element 201 may operate as a wave director or a reflector by switching the above control voltage.

When the reactance circuit 202 is constituted in this way, it is easy to make one fixed resonance element or some fixed resonance elements operate as a wave director and make the remaining resonance elements as a reflector by simply switching the control voltage.

In the example shown in Fig. 5, although the diode D1 is used as a switching element, the connection between the electrodes may be on-off controlled such that an MEMS (microelectromechanical system) element is used and the drive voltage is applied.

Next, the structure of an antenna device according to a third embodiment is shown in Fig. 6. Different from the antenna device of the first embodiment shown in Fig. 1, in this example, three primary radiators 1a, 1b, and 1c are contained as the primary radiator. This is to solve a problem in that, since a plurality of resonance elements in the resonance element array is provided in a relatively large area, when a single primary radiator is used, the power supply to resonance elements away from the central axis of the primary radiator is reduced. That is, out of the plurality of resonance elements provided in the resonance element array 200,

the middle primary radiator 1b takes charge of substantially one third in the middle, the primary radiator 1a takes charge of substantially one third in the upper portion in the drawing, and, in the same way, the primary radiator 1c takes charge of substantially one third in the lower portion. In this way, a more uniform power is radiated to all the resonance elements.

Next, the structure of an antenna device according to a fourth embodiment is shown in Fig. 7. Here, reference numeral 6 represents an opening hollow resonator having an opening in the direction of the lens 3. An excitation element 7 is disposed inside the resonator 6. The same resonance element array 200 as shown in Fig. 2 is disposed in the opening portion of the opening hollow resonator 6. This opening hollow resonator 6 resonates in the TE10 mode and is disposed such that its polarization plane is parallel to the length direction (direction of the extension of linear conductors) of the resonance elements provided in the resonance element array 200. Therefore, an electromagnetic field is given to each resonance element in the resonance element array 200 in the opening surface of the opening hollow resonator 6 by excitation of the excitation element 7. At this time, in the same way as in the cases of the first and second embodiments, the resonance elements in resonance re-radiate an electromagnetic wave as a wave director. Therefore, in the same way as in the cases of the first and second embodiments, the direction of beams which are collimated by the lens 3 is controlled by switching the position of the resonance devices operating as a wave director.

Next, the structure of an antenna device according to a fifth

embodiment is shown in Fig. 8. Although the lens 3 is used as a collimating means in the first to fourth embodiments, in the example shown in Fig. 8, a reflector 8 is used as a collimating means. That is, the reflector 8 as an offset parabola reflector is disposed at the position where an electromagnetic wave radiated from fixed resonance elements in the resonance element array 200 is reflected. When the resonance element 201f provided in the resonance element array 200 is excited by an electromagnetic wave from the primary radiator and operates as a wave director, beams are formed in the direction shown by optical paths 5f. Furthermore, when the resonance element 201d is excited by an electromagnetic wave from the primary radiator and operates as a wave director, beams are formed in the direction shown by optical paths 5d. In this way, the direction of beams can be electronically tilted by controlling a voltage applied by the control portion.

Next, the structure of an antenna device according to a sixth embodiment is shown in Fig. 9. Fig. 9 is a front view of the resonance element array. In this example, a plurality of resonance elements 201 of linear conductors are arranged on the dielectric substrate 203 such that the resonance elements 201 are parallel to each other and are tilted so as to be substantially 45 degrees to the direction of the arrangement. The structure where the reactance circuit 202 is connected to each resonance element 201 is the same as what is shown in Fig. 2.

In this way, an electromagnetic wave of a linearly polarized wave whose plane of polarization is tilted substantially 45

degrees to the horizontal plane is transmitted such that the plurality of resonance elements 201 are arranged so as to be substantially 45 degrees tilted to the arrangement direction. Therefore, when transmission radio waves in the direction of the front from the millimeter wave radar are received using an antenna device of the same structure, their plane of polarization and the plane of polarization of the antenna device cross each other at right angles. Therefore, when the antenna device of this structure is applied to millimeter wave radars, the problem of interference to other devices can be reduced.

Next, the structure of the main portion of an antenna device according to a seventh embodiment is shown in Fig. 10. In Fig. 10, reference numeral 200 represents a resonance element array and the structure is the same as shown in Fig. 2. Reference numeral 1 represents a primary radiator of an electronically controlled wave-director array antenna. That is, a feed element 11 is contained in the center and a plurality of non-feed elements 12a to 12f where a reactance is loaded is disposed around the feed element. The non-feed elements 12a to 12 f are resonance elements where a variable reactance circuit is contained in the middle portion, and an antenna in which the reactance of the variable reactance circuit is loaded is constituted. The structure of the variable reactance circuit is the same as those shown in Figs. 4 and 5. Accordingly, the equivalent electric length changes in accordance with the reactance value and the resonance elements are selectively operated as a wave director or reflector.

The feed element 11 operated as a radiator and the radiation

pattern variously changes depending on the feed element 11 and the non-feed elements 12a to 12f. Here, the radiation pattern in the direction of the resonance element array 200 is changed. For example, a control voltage to the variable reactance circuit of the non-feed elements 12a to 12f is controlled so that the center of the radiation pattern may be directed to the direction of resonance elements which are made to operate as a wave director on the resonance element array 200.

Thus, even if the plurality of resonance elements provided in the resonance element array is widely distributed, an electric power can be uniformly supplied to the resonance elements on the resonance element array. Also, an electromagnetic wave radiated from fixed resonance elements can be received by the primary radiator at a uniform sensitivity.

Moreover, in each embodiment shown in the above, a variable reactance circuit in which the reactance is changed by application of a voltage is provided in order to control the resonance frequency of fixed resonance elements, but a control circuit may be provided so that the equivalent electric length of resonance elements may be changed by controlling others except for the change of applied voltage.

Next, the structure of an antenna device according to an eight embodiment is described with reference to Figs. 11 and 12.

In the example shown in Fig. 2, a plurality of resonance elements 201 was formed on a dielectric substrate 203 and a variable reactance circuit 202 was provided substantially in the middle of each resonance element 201, but in the example shown in

Fig. 11, variable resonance circuits 202 are provided at both ends of each resonance element 201 and in addition, auxiliary elements 205 are formed outside the circuits 202. The other structure is the same as that shown in Fig. 2. The control portion 4 selectively gives a control voltage to the plurality of variable reactance circuits 202 through the control signal line 9. For example, when one resonance element 201 is made completely resonant or substantially resonant at a frequency in use and the other resonance elements are made non-resonant, the resonant or substantially resonant resonance elements operate as a wave director.

Fig. 12 shows a concrete example for the variable reactance circuit 202 shown in Fig. 11. In this example, the variable reactance circuit 202 is composed of a capacitor C and a switching circuit 204 parallel to the capacitor C. The switching circuit 204 is an MEMS element which is turned on and off by application of a control voltage through the control signal line 9.

When the switching circuit 204 is in the off state, the auxiliary element 205 is connected to the end portion of the resonance element 201 through the capacitor C. Furthermore, when the switching circuit 204 is in the on state, the auxiliary element 205 of a fixed electric length is connected to the end portion of the resonance element 201. In this way, the equivalent electric length of the resonance element is switched. Thus, since the auxiliary elements 205 are connected to both ends of the resonance element 201, the symmetry of the resonance element can be maintained.

Fig. 13 is a front view of a resonance element array 200 constituting the main portion of an antenna device according to a ninth embodiment. In the resonance element array 200, element antennas made up of a resonance element 201, resonance circuits 202 and auxiliary elements 205 are arranged on the dielectric substrate 203 so as to be parallel to each other and substantially 45 degrees tilted to the arrangement direction.

Thus, in the same way as in the case of the antenna device shown in Fig. 9, an electromagnetic wave of a linearly polarized wave in which the plane of polarization is substantially 45 degrees tilted to the horizontal plane can be transmitted and received.

Next, a radio device according to a tenth embodiment is described with reference to Fig. 14. In Fig. 14, A CPU 11 outputs a transmission signal of a digital code sequence. A DA converter 12 converts the signal into an analog signal. A low-pass filter 13 makes unnecessary high-frequency signals attenuated. A mixer 14 mixes an oscillation signal of an RF oscillator 15 and an output signal from the low-pass filter 13. A bandpass filter 16 makes output signals of the mixer 14 pass only in a fixed frequency range, a power amplifier 17 power amplifies the signals and makes the signals radio-transmitted from an antenna 19 through a circulator 18. A reception signal received at the antenna 19 is input to a low-noise amplifier 20 through the circulator 18. The low-noise amplifier 20 amplifiers the reception signal, and a bandpass filter 21 makes unnecessary signals out of the output signals from the low-noise amplifier 20 attenuated. A mixer 22

mixes an oscillation signal of the RF oscillator 15 and the output signals from the bandpass filter 21. A low-pass filter 23 makes unnecessary high-frequency components out of the output signals from the mixer 22 attenuated. An AD converter 24 converts the signals into digital data sequences. The CPU 11 processes the data sequences in order. Furthermore, the CPU 11 controls a beam direction control device 25 such that the directivity direction of the antenna 19 (center of the directivity pattern) is directed to a fixed direction. The beam direction control device 25 corresponds to the control portion 4 in each embodiment which has been described and the directivity of the antenna is controlled by making fixed resonance elements of the resonance element array 200 excited or by controlling the reactance of fixed reactance circuits.

Next, a radar according to an eleventh embodiment is described with reference to Fig. 15.

Fig. 15 is a block diagram showing the whole structure of a radar. Here, a VCO 31 changes an oscillation frequency in accordance with a control voltage output from a DA converter 48. A transmission wave modulation portion 47 outputs digital data of a modulation signal to the DA converter 48 in order. Thus, the oscillation frequency from the VCO 31 is FM-modulated into a triangular wave signal in succession.

An isolator 32 transmits the oscillation signal from the VCO 31 to the side of a coupler 33 and prevents a reflection signal from entering the VCO 31. The coupler 33 transmits the signal coming through the isolator 32 to the side of a circulator 34 and

gives a part of a fixed distribution ratio of the transmission signal as a local signal Lo to a mixer 36. The circulator 34 transmits the transmission signal to the side of an antenna 35 and gives a reception signal from the antenna 35. The antenna 35 transmits the transmission signal where a continuous wave from the VCO 31 is FM-modulated into a triangular wave signal, and receives a reflection signal from a target. Furthermore, the direction of the beam is periodically changed over the range of detection angles.

The mixer 36 mixes the local signal Lo from the coupler 33 and the reception signal from the circulator 34 to output an intermediate-frequency signal. An IF amplifier circuit 37 amplifies the intermediate-frequency signal at a fixed amplification degree in accordance with the distance. An AD converter 38 converts the voltage signal into a sampling data sequence. In a DC elimination portion 39, an average value of a fixed sampling interval constituting an object to be processed at a backstage FET out of sampling data sequences obtained by the AD converter 38 is determined as a DC component, and the DC component is subtracted from each data of the whole sampling intervals.

Regarding the data of the above sampling intervals in which the DC component is removed, an FFT operation portion 40 analyzes their frequency components. A peak detection portion 41 detects maximum positions regarding frequency components having levels beyond a predetermined threshold value.

A distance and speed calculation portion 42 calculates the distance from the antenna to a target and the relative speed based

on the frequency of a beat signal (upbeat signal) in a modulation interval where the frequency of a transmission signal gradually increases and the frequency of a beat signal (downbeat signal) in a modulation interval where the frequency of a transmission signal gradually decreases, and outputs these to a display 44.

The DC elimination portion 39, the FFT operation portion 40, the peak detection portion 41, and the distance and speed calculation portion 42 are assembled into an operation element 43 such as a DSP (digital signal processing circuit), etc.

A beam direction control device 46 controls the directivity direction of the antenna 35. This beam direction control device 46 corresponds to the control portion 4 shown in each embodiment, and the directivity of the antenna is controlled by making fixed resonance elements in the resonance element array 200 excited or by controlling the reactance of fixed reactance circuits.

A synchronizing signal generator 45 gives a synchronizing signal to the beam direction control device 46 and the display 44.

The display 44 displays a two-dimensional radar detection image based on an the synchronizing signal and distance from the synchronizing signal generator and the output signal from the speed calculation portion 42.

Industrial Applicability

As described above, in an antenna device according to the present invention, the beam scanning is speeded, power consumption for the beam scanning is reduced, and the reliability can be increased. Furthermore, when required, the beam direction can be

directed in any direction and the beam radiation pattern can be changed. Accordingly, an antenna device of the present invention is valuable for radio devices and mobile radars.